DOCUMENT RESUME

ED 235 041 SE 043 334

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TITLE Iron Smelting. Third World Science.
INSTITUTION University Coll. of North Wales, Bangor (United Kingdom). School of Educaton.
SPONS AGENCY Training Services Agency, London (England).
PUB DATE 82
NOTE 26p.
AVAILABLE FROM The Centre for World Development Education, 128 Buckingham Palace Road, London SW1W 9SH.
PUB TYPE Guides - Classroom Use - Guides (For Teachers) (052)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Chemical Industry; Cultural Activities; *Developing Nations; Elementary School Science; Foreign Countries; Intermediate Grades; *Metal Industry; *Metallurgy; *Science Activities; Science Education; Secondary Education; *Secondary School Science
IDENTIFIERS *Iron (Metal); *Third World Science Project; United Kingdom

ABSTRACT

This unit, developed by the Third World Science Project, is designed to add a multicultural element to existing science syllabi (for students aged 11-16) in the United Kingdom. The project seeks to develop an appreciation of the: boundless fascination of the natural world; knowledge, skills, and expertise possessed by men/women everywhere; application of knowledge and skills to solve the practical problems of everyday life; impact of modern technology in the world; and the influence of the cultural background on the perception of knowledge, problems, and solutions. The unit consists of four sections and references. The first section considers events leading to the beginning of the Iron Age and smelting the ore today. A diagram showing a blast furnace operating and producing pig-iron is included. The second section is a discussion of iron-smelting in Uganda, an indigenous chemical industry that has been used to introduce African students to basic scientific principles. Provided in the third section are discussions of bellow making (including instructions for constructing bellows), iron-smelting, and end-products of the smelting process. The unit concludes with some suggested class activities, including the extraction of iron from iron ore. (JN)

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IRON SMELTING

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THIRD WORLD SCIENCE

Third World Science seeks to develop an appreciation of:

1 The boundless fascination of the natural world

2 The knowledge, skills and expertise possessed by men and women everywhere

3 The application of knowledge, skills and expertise to solve the practical problems of everyday life

4 The impact of modern technology in the third world

5 The influence of the cultural background on the perception of knowledge, problems and solutions

The following Units have been designed to fit into existing science syllabuses in the United Kingdom:

CARRYING LOADS ON HEADS: CHARCOAL: CLAY POTS:
DENTAL CARE: DISTILLATION: ENERGY CONVERTORS:
FERMENTATION: HOUSING: IRON SMELTING: METHANE DIGESTORS:
NATURAL DYES: PLANTS AND MEDICINES: SALT: SOAP.

The method of use is not closely prescribed. As resources teachers may use them in different ways though suggestions are offered. Feedback is invited from teachers concerning (a) the use made of the material (b) pupils reactions, if possible in their own words, and (c) suggestions for improvements, additions etc.

Please send feedback, ideas and requests to:

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IRON SMELTING

Teacher's Notes

There is a wealth of science to be learned at the blacksmith's e.g. distinguishing between metals and non-metals; the three states of matter, melting and boiling points, physical and chemical change, burning and air, heat transfer-conduction, convection and radiation.

The unit begins with a very brief historical outline of the events leading to the beginning of the Iron Age, followed by the process of reducing the oxide to the metal.

The article by Mr. John Haden follows on 'Iron Smelting in Uganda'. John Haden spent four years (1968-1972) on an overseas development administration contract with the government of Uganda. For the first three, he taught at Mvava Secondary School, Arua, where he developed the smelting project included in this unit. His last year he spent at Makerere College School, Kampala. As one might imagine, he had a keen interest in developing chemistry courses to the needs of developing East Africa.

There are two contributions by third year pupils of Lubushi Seminary, Zambia - one dealing with 'bellow-making' and the other with 'iron-smelting' and some 'end-products'. The unit concludes with some suggested class activity.

IRON SMELTING

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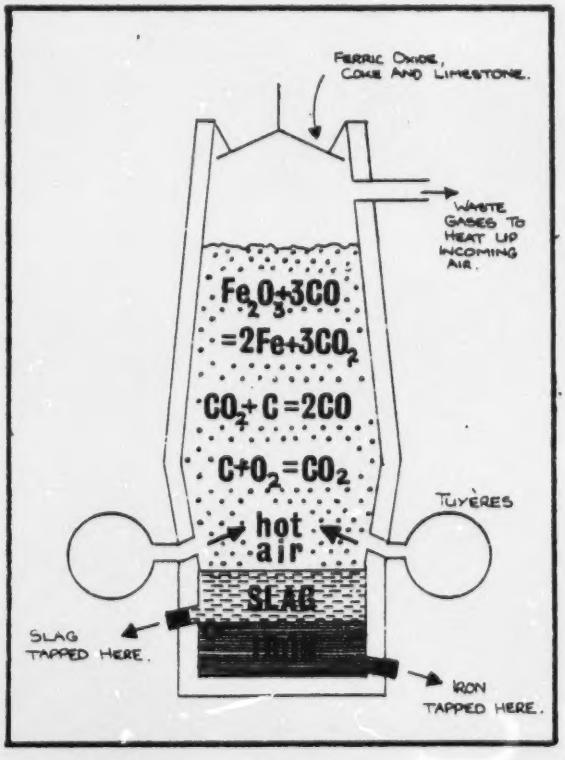
IRON SMELTING

The part played by metals in the story of mankind is a very important one. From time to time a new metal has been discovered and put to widespread use, changing the whole character of a civilisation and altering the way of life of the people. Thus historians refer to the period following the discovery of the alloy bronze as the Bronze Age. Once this alloy had replaced flint and bone as a material for making tools and shaping weapons of war, the people using it were able to conquer and enslave the more backward peoples who still relied on the old weapons. Later on the superior qualities of iron were discovered and methods of producing it in quantities sufficient to supply the needs of the time were invented. This age goes down in history as the Iron Age, stretching from soon after the dawn of recorded history to very near our own times. During the Industrial Revolution one of the most significant changes was the substitution of steel for iron, and the 19th and early 20th centuries might be known to future historians as the Age of Steel.

There is little doubt that iron, together with its carbon alloy steel, is the most important metal produced industrially today. The common ones containing iron are nearly all oxides, either the *red oxide* Fe_2O_3 or the *black magnetic oxide* Fe_3O_4. The process of reducing the oxide to the metal is carried out in a *blast furnace* (See diagram).



Blast furnace.

A medium grade ore might contain 50% of metal. In this case it would be mixed with roughly an equal quantity of *coke* and about one third of its weight of *limestone*. One purpose of this *limestone* is to form a *flux* or *scum* (called slag) with the impurities, especially *silicon* and *aluminium* compounds. This floats on the top of the molten metal at the bottom of the furnace and can be tapped off at a higher level than the metal itself. The slag solidifies and is then crushed, to be used in the manufacture of cement and road-making material.

The furnace is kept going night and day by a blast of hot air, and something like *four tons of hot air are blown through the furnace for every ton of iron made*. The coke burns in this blast of air to form carbon monoxide. The carbon monoxide reduces the *iron oxide* in the main body of the furnace according to the equations:

$$3CO + Fe_2O_3 \longrightarrow 2Fe + 3CO_2$$

Ferric oxide

$$4CO + Fe_3O_4 \longrightarrow 3Fe + 4CO_2$$

Triferric oxide

The carbon dioxide produced is reduced again to carbon monoxide by more coke higher up in the furnace and in turn attacks more oxide. The heat of the furnace causes the *limestone* to break down to *calcium oxide* and *carbon dioxide*. The *calcium oxide* forms the *slag*, whilst the *carbon dioxide* is reduced to *carbon monoxide* by coke in the body of the furnace and this supplements the *carbon monoxide* formed from the burning of coke in the *oxygen* of the air blast.

$$CaCO_3 \longrightarrow CaO + CO_2$$

Limestone — Calcium oxide

$$CO_2 + C \longrightarrow 2CO$$

The molten iron runs to the bottom and is drawn off from time to time. The hot gases escaping from the top are used to heat the incoming air blast. In this manner the heat loss is reduced to a minimum, and so fuel is saved.

The iron so produced may contain as much as 4% or 5% of carbon, partly as separate crystals of *graphite*, partly as a *carbide of iron*, embedded in the surrounding iron. This gives it a grey colour and makes it rather brittle. Consequently it is not very strong. Its main use is for the manufacture of articles such as saucepans, buckets, fittings and stands where great strength is not required. The *retort* stands in the laboratory are probably made of this form of iron. Most of the articles produced are obtained as castings by pouring the molten metal into specially prepared moulds where it can solidify into the shape required; for this reason the impure iron is known as *cast iron*. It can be used successfully in this way because, like water, it expands slightly on solidifying, thus giving a very faithful reproduction of every feature of the mould.

Wrought Iron

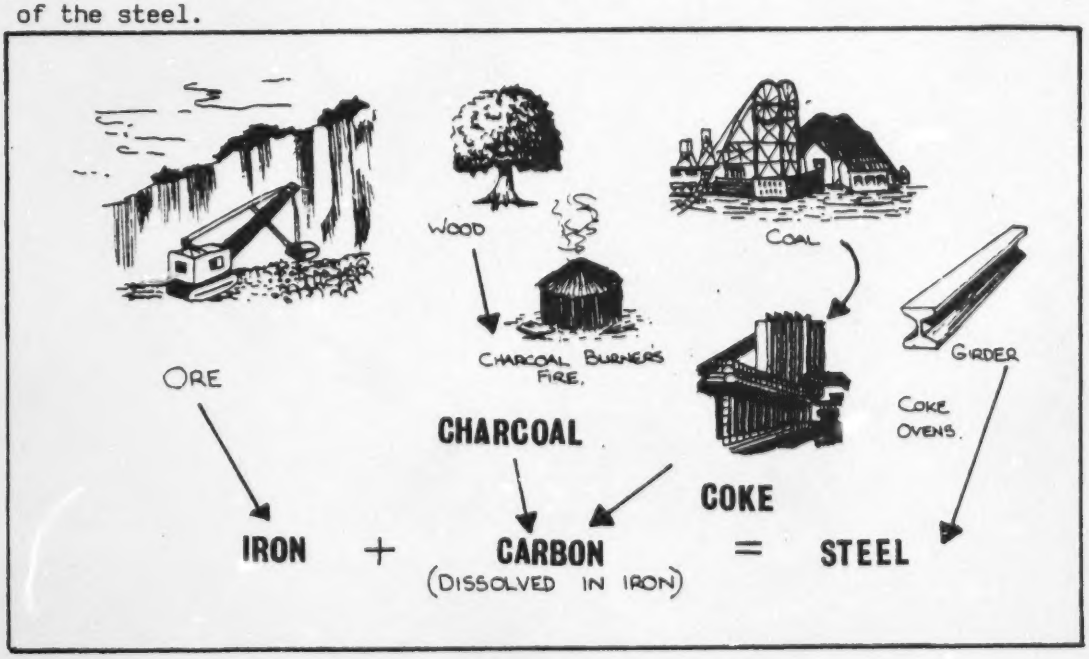
For centuries this was the strongest form of iron, used by the blacksmith because it can be beaten out and shaped easily at a bright red heat into bars, girders, fairly sharp edged tools, and many other things. Unlike cast iron it contains little carbon. It is produced from cast iron by heating in a furnace with more iron oxide. The oxygen from this oxide combines with the carbon to give oxides of carbon which escapes, and many of the other impurities are squeezed out of the semi-solid mass as a slag when it has cooled sufficiently. Unlike the advent of large scale methods for steel production most of the iron produced was used in this form. It is still used where the iron has to be bent (e.g. in the making of ornamental iron gates and in the fashioning of horseshoes) and for small articles such as nails, and the fittings for agricultural implements.

SMELTING THE ORE TODAY

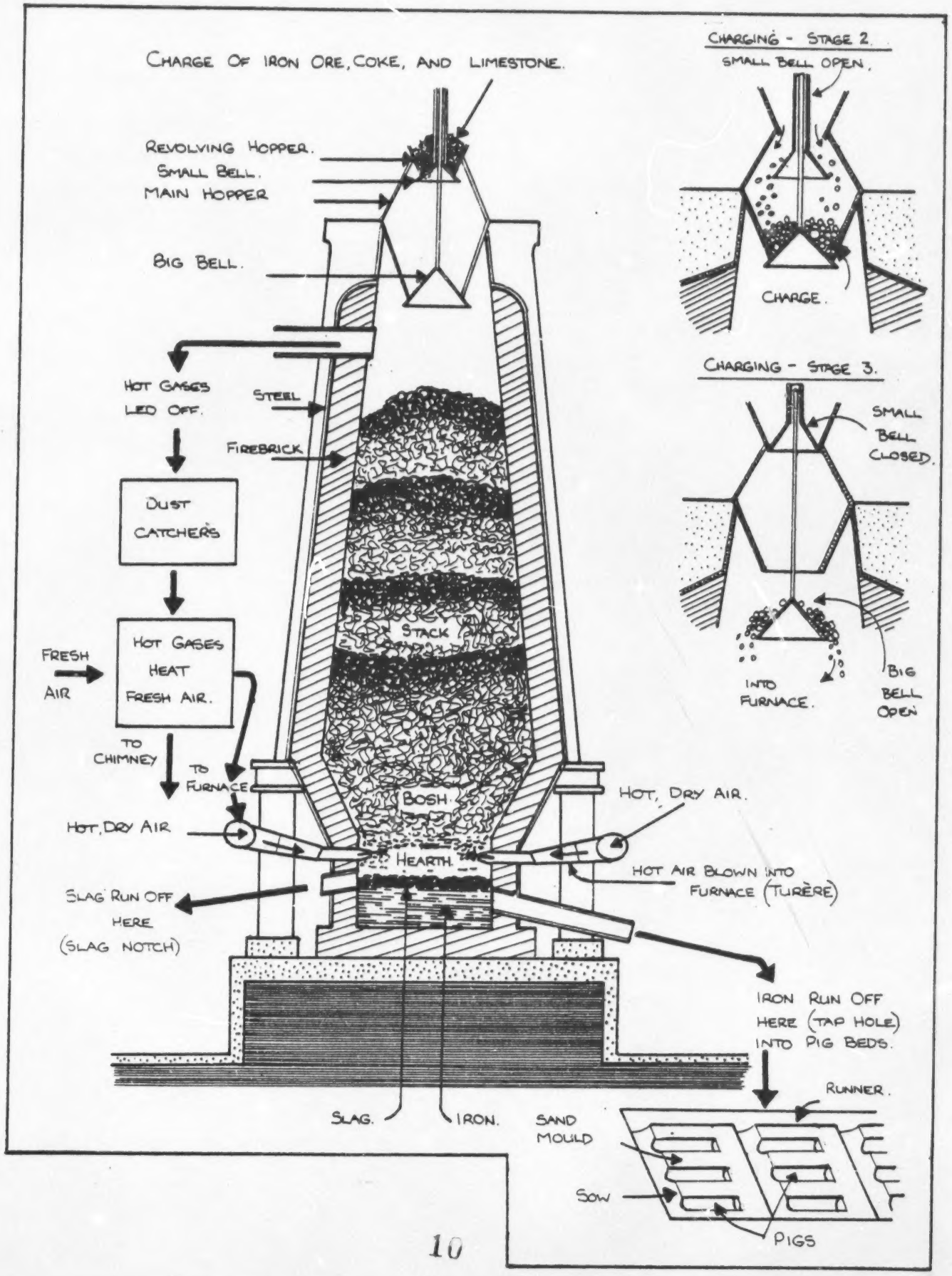
The modern furnace is very different from the simple charcoal fires of long ago. It is the first thing one notices on visiting an iron works, for its main portion is a tower about 30 metres high and 10 metres wide at the base. It is built of thick steel plates lined with specially shaped fire-bricks. Near the furnace are piles of broken ore, of limestone, and of coke. These are carried up steep runways to the top of the furnace in small trucks or *skips* and the proper quantities of each unloaded into it at regular intervals (see diagram overleaf).

The furnace is kept alight for two years at a time, day and night, seven days a week. Every four hours or so the furnace-men tap first the slag and then the iron. Both are white hot and when the plug is broken the molten iron gushes out. It is caught in a large ladle and taken straight to the steelworks. It used to be run out into channels and rough moulds made in sand. These rough moulds were called "pigs", and so at this stage, iron is still called "pig-iron"(see diagram).

Therefore there are only two important forms of iron; *wrought iron*, which is very nearly *pure* iron, and *cast iron* which is very impure iron in which the proportions and the nature of the impurities may vary quite a bit. Steel that is made today, though it contains carbon and perhaps other elements, always has a precise composition; it is a metal that has been specially planned to meet certain definite needs. In this planning the proportion of carbon to be present is extremely important, for quite a small increase in the amount of carbon will make quite a large increase in the hardness of the steel.



A BLAST FURNACE.



Iron Smelting in Uganda

by John Haden

This is yet another indigenous chemical industry that can be used to introduce African pupils to basic scientific principles.

Local Technology

As a chemistry teacher an attempt by the school to show interest in village life, meant finding any local activity that could be described as both traditional and technological, and encouraging students to find out as much as they could about that activity from the elders in their villages.

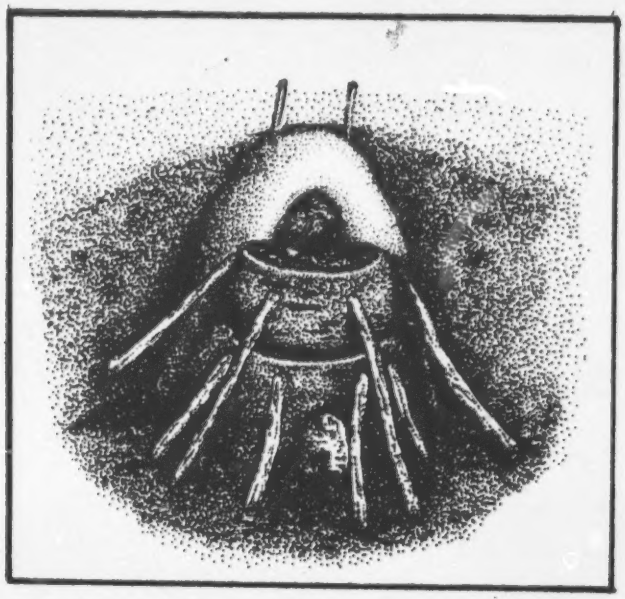
What started as a conventional discussion of iron as a reducing agent led to a study of charcoal burning - an important source of school fees for several local parents and a cooking fuel for the more affluent. This led directly to the local blacksmith, who operated a crude forge burning charcoal, and to the whole question of traditional methods of iron smelting.

Although no smelting has been done in West Nile (N.W. Uganda) since the early 1940's, a small local tribe, the Okebu, have a reputation as expert iron workers, and are also remembered as the tribe that held the monopoly of smelting. A group of students, including some Okebu, agreed to investigate iron-smelting techniques and also look into the status of the smiths in the cultural *milieu* of the tribe.

To do this they first had to gain the co-operation of the Okebu elders, their only source of information. Those of the elders who had smelted iron in their youth had to be persuaded to pass on to the students what was, to them, still a jealously guarded secret.

Fortunately suspicion was eventually overcome by pointing out the need to preserve a skill that was rapidly disappearing. We built an Okebu furnace at the school (see drawing) under the guidance of the elders; while another group looked into the supply of raw materials, discovering, as they did so, a highly complex pattern of trading in ore and finished iron goods.

Apart from the obvious necessities of good ore and charcoal, a third essential raw material, referred to by the Okebu as *iza* - literally: *excrement of iron* - proved difficult to identify. At first, conditioned by our knowledge of a blast furnace we thought this must be *flux*, but we then heard that this would be the first example of *flux* in African iron smelting, and thus very unlikely. *Iza* eventually turned out to be a *conglomerate of charcoal*



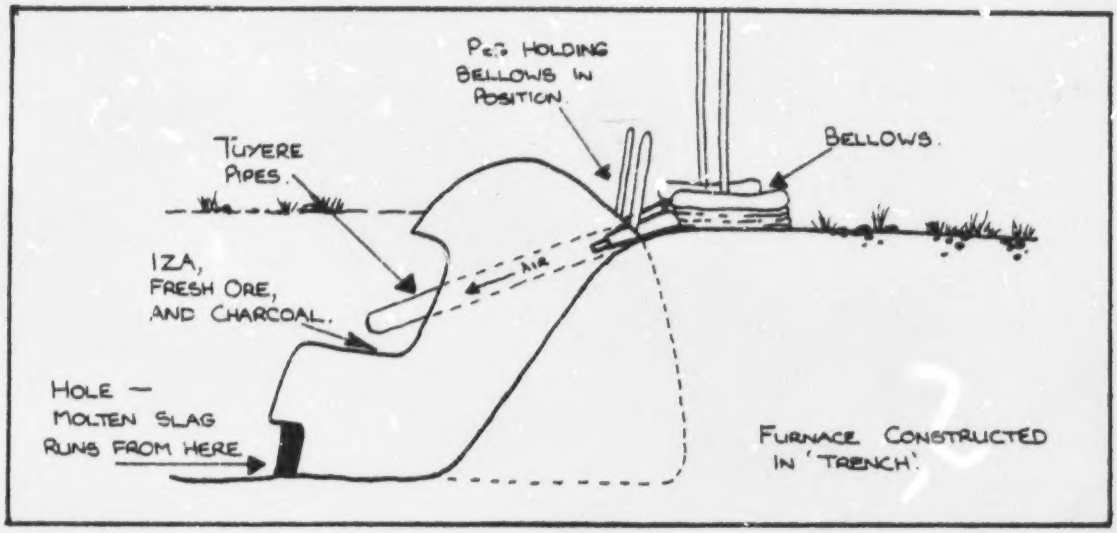
Okebu iron-smelting furnace

imbedded in a matrix of partially smelted ore, which was found around old smelting sites. This stimulated a survey of all known sites in the district - itself a valuable exercise - and the lack of success of our first smelt was confidently attributed by the elders to the poor quality and age of our *iza*.

In a school that did not teach beyond O-level, and with very limited laboratory equipment, we could only attempt crude gravimetric analyses of ore and slag samples. However, the results showed just how good the elders were at selecting suitable high-grade *limonite* and *magnetite*, and rejecting the ores with lower iron content. To check our results, we sent samples for a more professional analysis, to the Geological Survey Department at Entebbe, and their results confirmed the elders' choice

The actual smelting process is deceptively simple. For each charge of ore, a new *tuyere* pipe is built into the permanent structure of the furnace. A retaining wall of soft clay is then built around the base of a bed of charcoal, which supports a chimney of pieces of *iza* clustered around the mouth of the *tuyere*.

Fresh ore is packed around the *iza* and the furnace is fired by dropping burning charcoal down the chimney. The air draught through the *tuyere* is provided by a pair of pottery bellows covered with skin, and worked continuously by a relay of men. After several hours, molten slag begins to run from the base of the furnace, through the bed of burning charcoal; this mixture



Sectional view of primitive Okebu iron-smelting furnace.

provides the *iza* for the next smelt. Meanwhile, in the upper part of the furnace, the old *iza* has been reduced sufficiently to produce a spongy mass of *free iron*, which is then compressed into a lump by prodding the top of the furnace vigorously with a green-wood stake. This lump is broken out of the furnace and quenched in a pool of water.

The great beauty of the Okebu method is that in a morning's work, *a pile of ore, some charcoal and some unpromising-looking bits of slag* can be turned into a lump of *wrought iron* which can be smithed immediately into a hoe or a spearhead. The process is very inefficient in terms of yields, and can only produce about 2 Kg of iron at a time, but it is direct, and provides a magnificent illustration of carbon reduction.

Temperature control is critical to the smelting process. The furnace must be hot enough to melt the ore - about 900°C - and to ensure intimate mixing of the ore burning charcoal. Carbon monoxide reduction can then occur at the ore/charcoal interface to produce a thin skin of spongy iron. If the furnace overheats - above 1300°C - the skin of iron will melt, (as it does in the modern blast furnace) and dissolve enough carbon to produce a cast-iron

useless to the Okebu smith who has no means of reducing carbon content. The smith controls the furnace temperature - estimated by peering down the *tuyere* and noting the colour of the furnace heart - either by pumping the bellows more vigorously and closing the top of the furnace with soft clay, or by opening out the top of the furnace.

Our first failure, followed by improved success in the next two attempts, led to an interesting discussion between the students and the elders on the causes for the failure. The elders suggested the traditional reasons, such as failure to apply the correct offerings, millet meal and chameleon, failure to exclude women from the smelting area, and failure to restrict the smelting groups to Okebu only. The students enjoyed trying to explain their more 'scientific' reasons. At our third attempt we produced enough iron to be forged into a hoe of traditional pattern by two smiths working with stone hammers and wood tongs. To complete the experience a detailed account of the whole process was completed and published in the *Uganda Journal*.

It is interesting to note that Uganda, with no coal, but plenty of iron ore and forests and a history of successful smelting, has at last got round to investigating the feasability of charcoal smelting on a large scale, and a pilot furnace was planned at Jinja. This demonstrates nicely that traditional techniques are not just interesting bits of tribal history, but could be the basis of a programme of industrial development.

Even so, for many generations to come, Uganda will continue to be an agricultural society, and it is the improvement of life in the villages that must be, and is, the major priority of her leaders. But as long as the young Ugandans who are fortunate enough to pass through her secondary schools, turn their backs on their village origins, this improvement is bound to be slow and limited. Somehow they must not only be taught chemistry, along with everything else that it is thought that they need to know, but also ways must be found of developing their confidence in themselves, and their origins and their respect for their past.

Contribution by Joseph Munba, Chrisanthus Mukuka and Joackin Musondah of Lubushi Seminary, Zambia.

BELLOW MAKING

1. Aim of the Project

Oxygen helps things to burn. In this project, compressed air is forced out to maintain a high constant temperature.

2. Its History

Many many years ago, people were using sharp pointed sticks to obtain food and for killing animals. This was a difficult task, because this caused or led them to the discovery of metals. It happened may be accidentally that someone threw a stone into the fire and after sometime the stone melted and that was found was metal. This came to the minds of the people that there was really something which could make their lives to proceed well by making better tools and weapons. The first metals to be discovered were; copper, gold and silver. This is about 7,000 years ago.

These metals were not hard enough to produce hard sharp strong flint. These metals were only used for ornaments and decorations because, they were considered to be less harder. Gold, copper and silver were to be mixed with other metals to produce an alloy, like bronze and brass.

It was found that these metals were not used for making any tool. Therefore they had to discover iron which was harder to produce a better tool and weapons.

Early iron worker must had something like a pair of bellows to make a strong blast of air to blow upon the red hot mixture of iron and burning charcoal. Blacksmiths or smiths, who were a common type of skilled workers until two generations ago, in a somewhat similar way had bellows in their smithies. But this was just their earth fire of fire coal, hot enough to soften the iron. Then when this was soft, they could hammer it upon the anvil.

Iron ores should have been discovered in many parts of the world, for iron is the most useful in the daily life of the all metals.

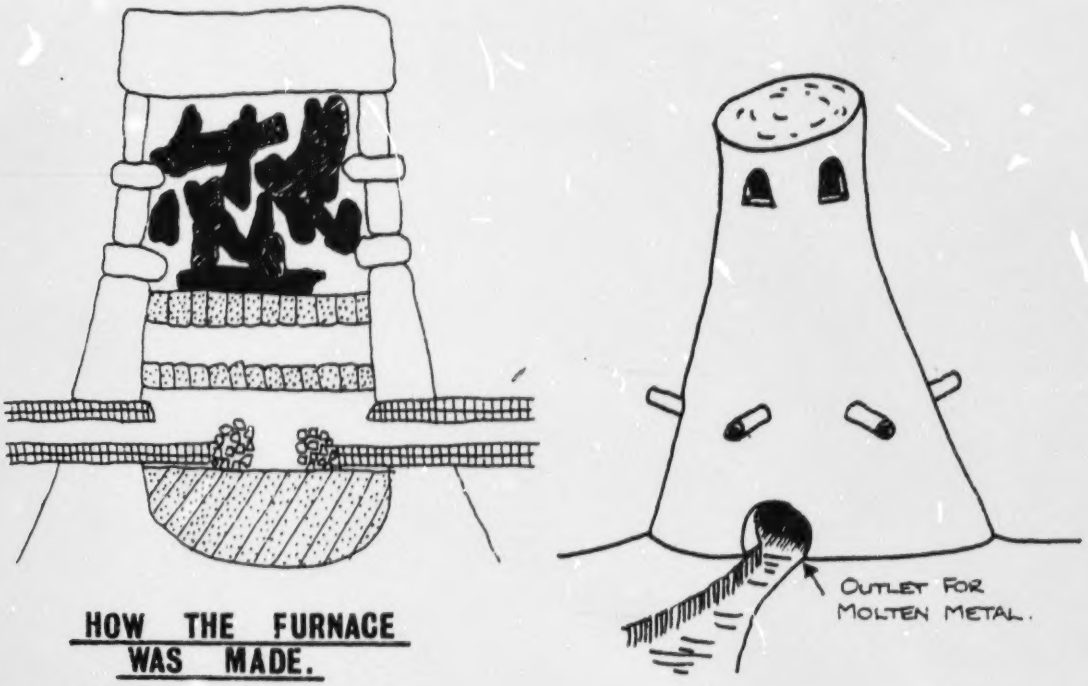
In discovering of all these metals, civilisation started to develop very badly.

Uses of Metal

To make digging hoes, axes, shaving instruments, knives, arrow heads, tongs, hammers, spears and wires etc.

EXTRACTION OF THIS METALS FROM ORES

1. Open pit mines were used to obtain the ores.
2. The ores were taken to the furnaces and were put in the furnace.
3. Fire was put into the furnace.
4. Compressed air from the bellows was forced into the flames.
5. The iron should reach the melting point which is about 1200°C.
6. The slag sinks to the bottom of the furnace and the metal floats on top and forces its way out where it pours into a well-made mould. The moulds were made according to the shape of the object they wanted to make. Things which were made at this point were; copper ingots used as money, wires for braclets and other decorations, etc.



HOW THE FURNACE WAS MADE.

Molten clay from the ant-hill which was always near the stream was used to build the furnace. This good soil because when dry, it produced a hard earth stone. The furnace was built near the ant-hill. It was made in a circular shape. Its diameter was 1-2 metres. It was big at the bottom and grew smaller as it went up. The top was flattened.

HOW CHARCOAL WAS MADE

"Special woods" were burnt in the open air. When wood was burnt enough (charcoal), it was taken away from the fire and water was poured on to stop it burning. This was done repeatedly until sufficient charcoal was obtained. Charcoal contained carbon.

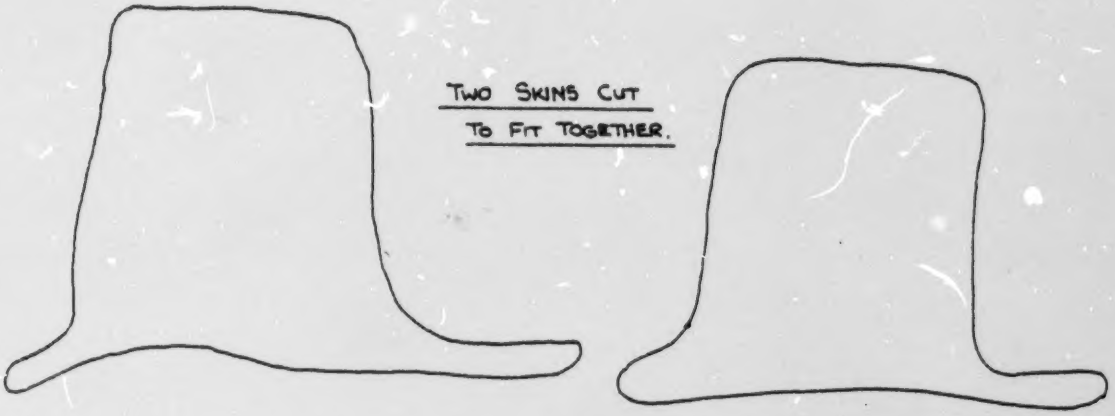
Names of trees from which woods were obtained are; Ndale, (hardwood with small leaves), Mubanga (hardwood). Musokolobe (not very hard), Mulombwa (hardwood), Musase and Saninga.

CONCLUSION: Bellows were very important at that time and without them man couldn't have lived a better life e.g. growing of crops for food. These things needed hoes and other tools to grow them and to make hoes axes, these things were to be melted by using bellows.

BIBLIOGRAPHY: References from the books called "Imilima ya bena Kale". Metals and Man and from the elders showed us how bellows were protected.

STEPS IN MAKING BELLOWS

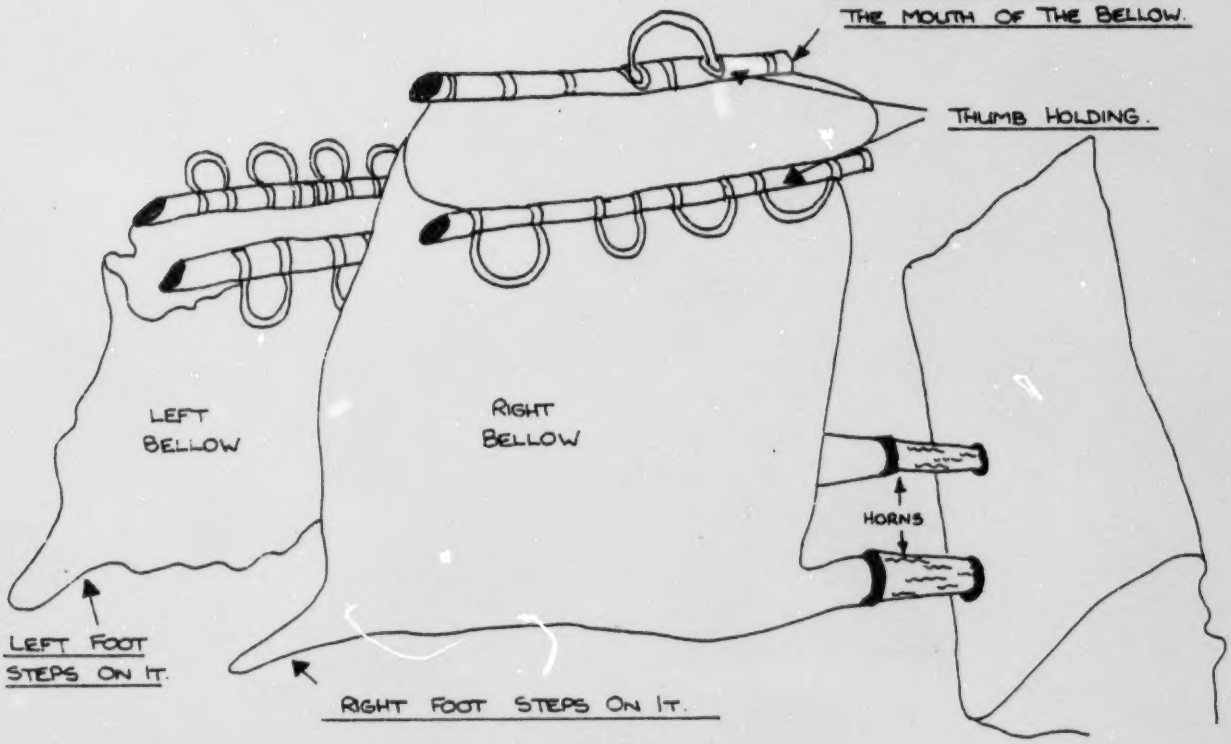
STEP 1



TWO SKINS CUT TO FIT TOGETHER.

SKINS WERE CUT ACCORDING TO THE SIZE OF THE BELLOWS THAT THEY WANTED TO MAKE.

STEP 2

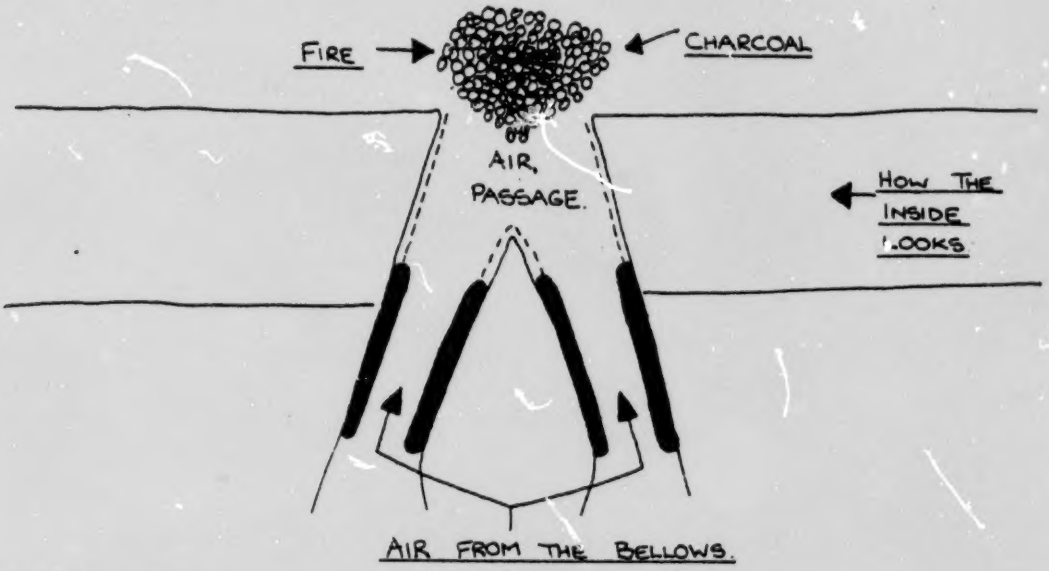


MATERIAL FOR MAKING BELLOWS

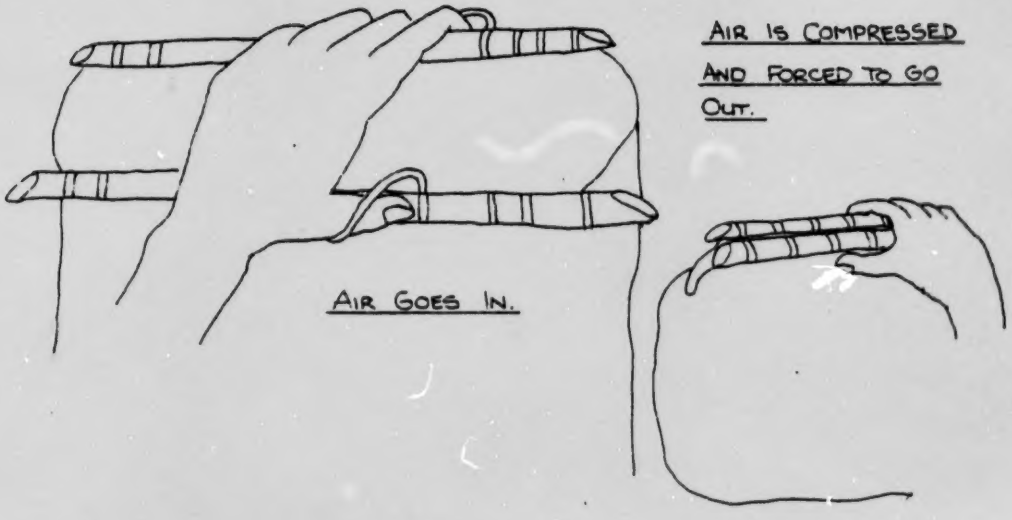
Small slices of skins or strings were used for sewing up the main skins. Suitable straight horns about 30 cm long were used to take out air from the bellows to the fire.

Medium thin skin such as chicken's skin, partridge's and water buck's skin etc. could be used. Four blades of wood, two to half a pair and the other two to the other pair. Castor oil or grease were put to the bellows to soften them.

STEP 3

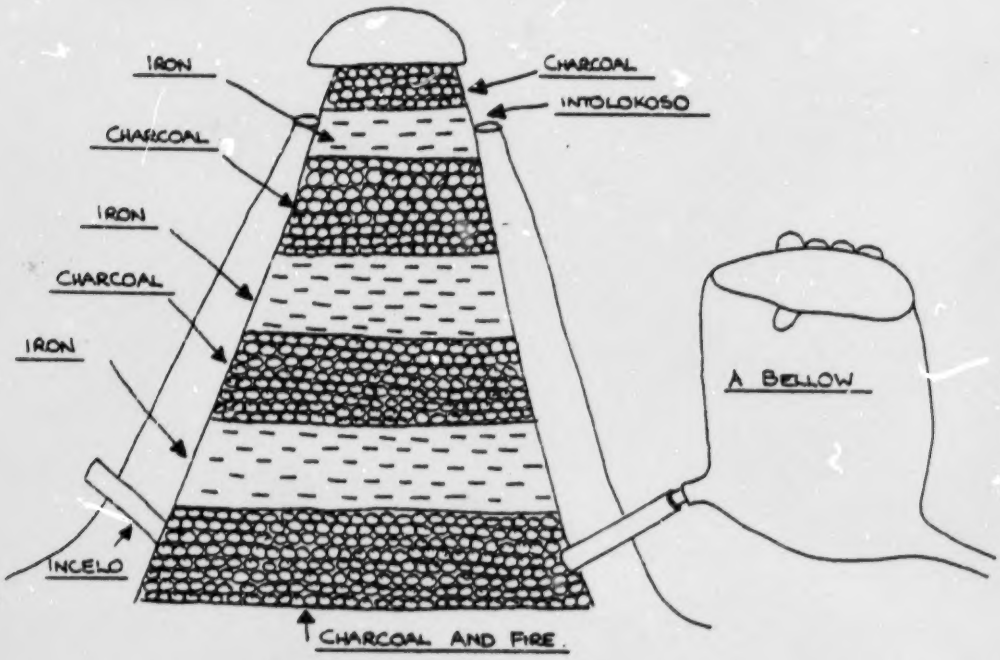


STEP 4

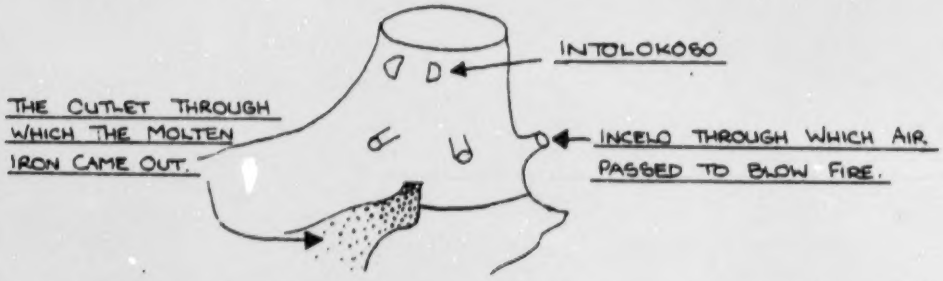


Contribution by Maximo Mwiwachola; Chowa Joseph; Charles Chapa; Muma Victor:-
3rd year Pupils of Lubushi Seminary, Zambia.

IRON SMELTING



Our forefathers used to smelt their minerals in a different way from today's. Before the minerals were exploited out they first built a big furnace in which they were smelting their minerals. In the furnace they were leaving some holes each having its own work. They were leaving Intolokoso, the outlets (incelo) so that when the air was glowing, it could pass through inceto to blow the fire which was made. They also prepared bellows to blow fire under the furnace before all the things mentioned above started working. Finally they had also to leave a hole at the bottom through which the mottern came out.



First of all, they were going in the forest and in small hills to look for minerals. In these hills they found precious stones which they knew were good. They were very bright, when they saw them. So they went back home

to take the tools for exploiting out the minerals. During this process they had to dig an open pit mine. This was a little bit deeper so that they could get the iron ores which were under the surface of the earth. They always didn't want those stones which were deposited near the surface because they were not useful and they had to leave them aside. The minerals were exploited in great quantity so that it could be enough to make tools from it.

How the fire was made and how they put ores in the furnace

They made fire in the furnace. After they had done this, the charcoal was put on top of the fire and then followed by the ores, then charcoal again, then ores until the furnace was full depending on how much ore they put in charcoal was always the last on top of the ores.

After they had done so then they started blowing the fire using bellows. The bellows blew the fire so as to enable the charcoal to catch fire, so when charcoal had cought fire it burned the ores and they melted forming a liquid called Mottern. It came out through the outlet. The residue was a special name for the mottern. When there was fire in the furnace then the blowing in of air was not to be done as much as before. The amount of air now needed was not great. This was because every piece of charcoal in there, was on fire. The blowing was just important to keep high temperature. When the ores have started melting the residue or mottern had its outlet. As far as we know that the iron is heavier than its rubbish so it had also its own outlet below. The mottern had its outlet, and the iron out it had to be on the other side of the furnace. So when it had finished melting they let it cool and afterwards it was collected.

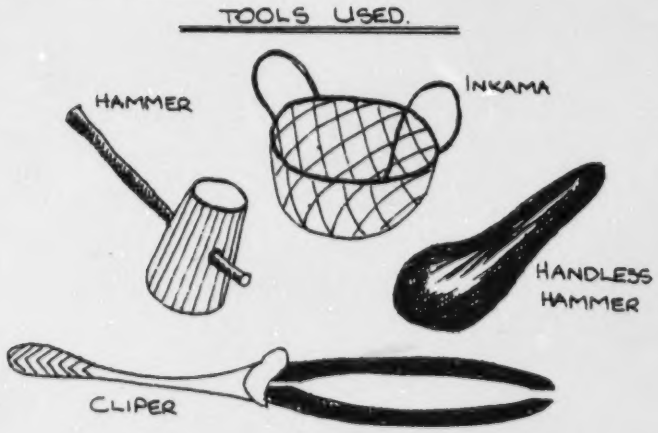
What they did with the iron (Pig Iron)

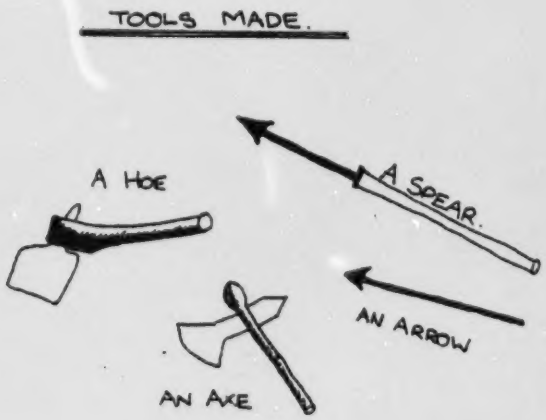
These people let the iron cool in the same containers. This iron which was let cool is called "Pig Iron". When it was cool they took it to their homes. At home they again started heating the "Pig Iron". When this is done they then hit it with a hammer to make it in proper shapes. After this they started making things from these pieces according to their sizes.

The things made from this iron

The pieces of iron which were cut in small sizes were put on the fire again so that, they could easily be made into tools. When they had taken this out of the fire they started hammering the metal with a hammer. They used a cliper to hold this hot metal. When it was well flattened they again

hit so that they didn't burn themselves. When they had finished hammering they took a heavy metal called (Indama) to level the metal. When it was well flattened they again heated it and hammered it. They repeated the process of heating and hitting until they made a hoe, with a very blunt digging edge. Now it was time to use a handless hammer to make the digging edge thin and a little bit sharp. For them to stop this they had to make sure that the edge would easily by sharpened. When they were finishing they heated the hoe for the last time. When the edge of the hoe was red hot they took if off the fire and dipped the edge into the water which was ready prepared for this purpose. The water was used to make the hoe strong and if this was not done the hoe could break just the very day one started using it. Axes were also made through the same process except bangles. Bangles are made from little piecies of iron cut about 2 cm wide and 4 cm long. This kind of bangle would be for a fat person, for when heated and hit it increased in size (expanded) and length, due to the expansion of the metal. When it was made to their liking they then curved it to make a beautiful bangle.





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2. Mr. Daniel Chola.
3. Milimo Ya Bina Kall.

Class Activity

1. Historical

   If you live in England, read about the early working of iron in the Weald of Kent and discover why ponds came to be called 'hammers'. Find out about the charcoal burning 'industry' which was still in existence in the 1940's. Find out when (a) coal, and (b) coke, came to displace charcoal in the production of iron. Why is there no longer an iron industry in the Weald?

2. If there is an iron works within reasonable distance of your school see if your science teacher can manage a visit. If not, perhaps there is a casting shop of some motor or other engineering industry to which a class visit can be arranged.

3. Find out what you can about (a) refractory firebricks and the special clays from which they are made, (b) casting sands and where they are found, (c) limestone for blast furnaces and where it is quarried.

   Perhaps you can collect specimens of (a), (b) and (c) to keep with your mineral collection.

4. How can iron be extracted from iron ore?
   This experiment brings out the practical usefulness of chemistry through an investigation into the problems of isolating iron from iron ore (see overleaf).

Extraction of iron from iron ore

Apparatus

Bunsen burner and asbestos square
Hard-glass test-tube, 75 x 12 mm
Test-tube holder
Magnet
Spatula
Red iron oxide
Powdered wood charcoal
M sulphuric acid

Procedure

Mix together a spatula measure of red iron oxide with a rather greater amount of powdered wood charcoal. Heat the mixture strongly in a hard-glass test-tube and allow it to cool. A black magnetic product is obtained which evolves hydrogen on treatment with molar sulphuric acid.

Note

Some samples of red iron oxide are magnetic and some become magnetic on heating. The magnet test alone is therefore not reliable evidence that iron is present.

The experiment shows that iron oxide can be reduced by carbon. This result may then be used to introduce the subject of the industrial production of iron and steel from iron ore.

IRON SMELTING

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THIRD WORLD SCIENCE

ACKNOWLEDGEMENTS

The Third World Science Project has been supported by a number of agencies and has drawn upon the expertise and goodwill of a vast number of individuals.

Pilot Project 1979-80 supported by the Overseas Development Fund

Writers: Trevor Roach, Philip Bladon Typing: Carole Johns
Graphics: George Robinson

Main Project 1981-82 supported by the Manpower Services Commission

Writers: Natalie Jones, Wyn Hughes Typing: Marjorie Eccles
Graphics: Karen Moss

In this phase of the project 100 sets of 14 Units have been produced and distributed to schools, teachers' centres and teacher training establishments. Draft material has been prepared for further Units.

Dissemination 1982-3 supported by the University of Wales

Faculty of Education Research and Publications Fund

Printing: University College of North Wales Print Unit

Distribution: The Centre for World Development Education, Buckingham Palace Road, London SW1W 9SH

The continued support and encouragement of Mr Dick Meakins of the CWDE is gratefully acknowledged

Sources The ideas and information incorporated in these Units come mainly from science teachers who are, or have been, teaching abroad. In some cases their pupils have also contributed. Some are known to us personally, others only through their letters, articles and books. We are very grateful to them all.

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